Wide-Band VLBA Receiver System for Astrometry and Navigation

Joseph Lazio

US VLBA Navigation and Reference Frame Workshop

Lorene Samoska, Melissa Soriano, Jose Velazco, Christopher Jacobs

Jet Propulsion Laboratory
California Institute of Technology

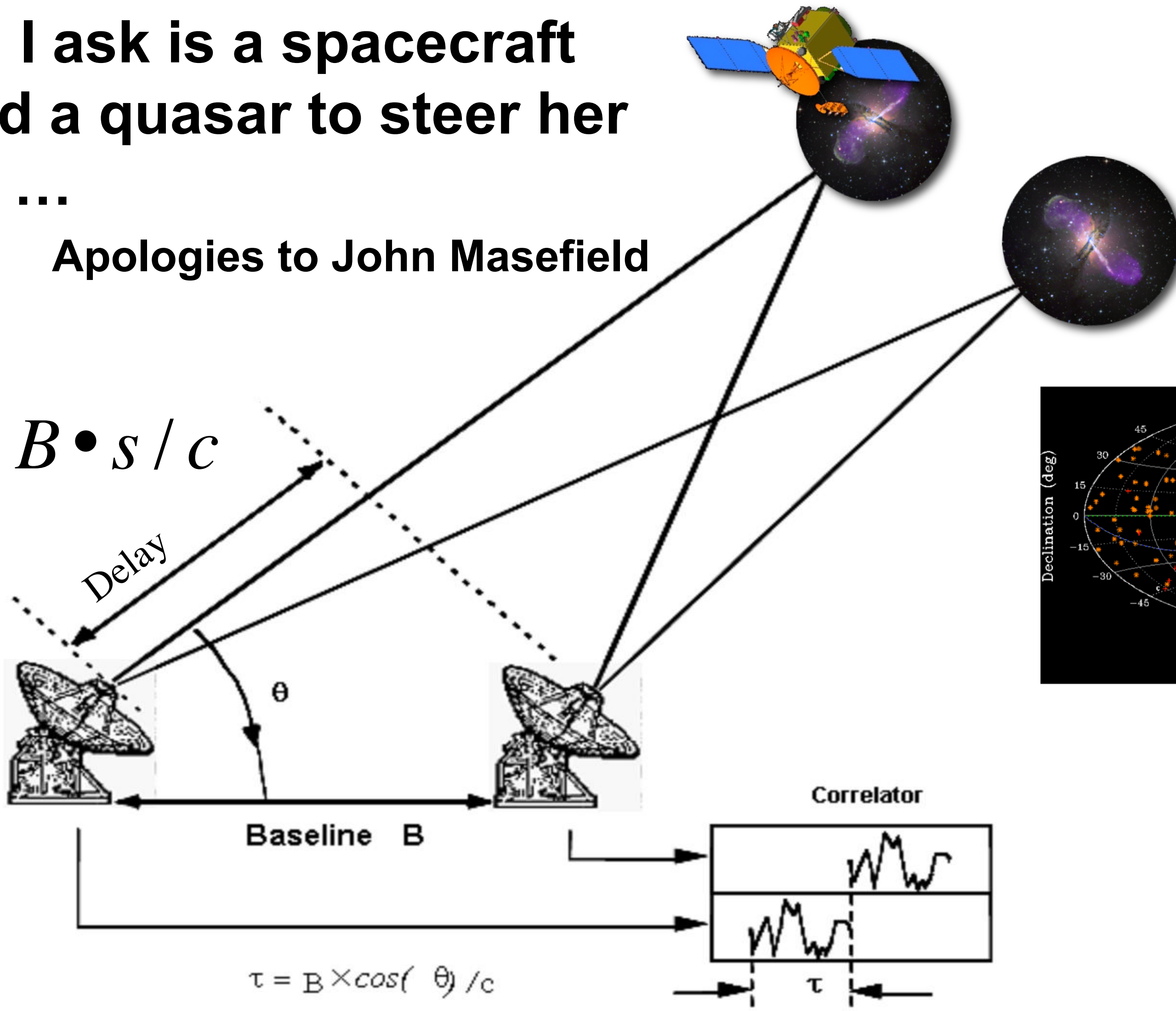
Motivation I

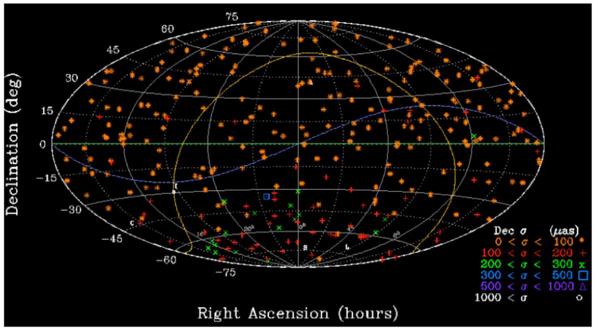
Wide-Band VLBA Receiver System for Astrometry and Navigation

All I ask is a spacecraft and a quasar to steer her by …

Apologies to John Masefield

$$\tau = B \bullet s / c$$

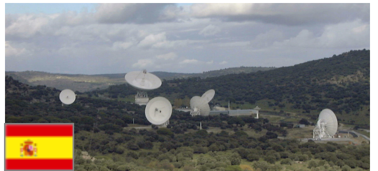




Credit: C.S. Jacobs

Motivation I

Wide-Band VLBA Receiver System for Astrometry and Navigation



Motivation II

Wide-Band VLBA Receiver System for Astrometry and Navigation

Frequency Bands Allocated by the International Telecommunication Union (ITU)

Band	> 2 million km from Earth		< 2 million km from Earth	
	Uplink	Downlink	Uplink	Downlink
S	2110–2120*	2290–2300	2025–2110	2200–2290
X	7145–7190	8400–8450	7190–7235	8450–8500
K	-	-	-	25500–27000
Ka	34200–34700	31800–32300	-	-

DSN Telecommunications Link Design Handbook, 810-005, 201
"Frequency and Channel Assignments"

*** Deep Space S-band not available at Madrid Deep Space Communications Complex**

VLBA vs. Spacecraft TT&C

Telecommunications, Tracking, & Command

Table 3: Receiver Frequency Ranges & Performance
as of July 2015

[1] Receiver Band Designation (*)	[2] Nominal Frequency Range [GHz]	[3] Typical Zenith SEFD [Jy]	[4] Center Frequency for SEFD [GHz]	[5] Typical Peak Gain [K Jy^{-1}]	[6] Baseline Sensitivity $\Delta S^{2048,2m}$ [mJy]	[7] Image Sensitivity $\Delta I_m^{2048,8h}$ [μJy beam^{-1}]
90 cm (a)	0.312 - 0.342	2742	0.326	0.077	(h) 39	(j) 266
50 cm (a,b)	0.596 - 0.626	2744	0.611	0.078	(h) 111	(k) 681
21 cm (c)	1.35 - 1.75	289	1.438	0.110	1.0	10
18 cm (c)	1.35 - 1.75	314	1.658	0.112	1.1	11
13 cm	2.2 - 2.4	347	2.269	0.087	1.2	12
13 cm (d)	2.2 - 2.4	359	2.269	0.085	1.3	12
6 cm (e)	3.9 - 7.9	210	4.993	0.119	0.7	6
7 ghz (e)	3.9 - 7.9	278	6.660	0.103	1.0	9
4 cm	8.0 - 8.8	327	8.419	0.118	1.2	11
4 cm (d)	8.0 - 8.8	439	8.419	0.105	1.6	15
2 cm	12.0 - 15.4	543	15.363	0.111	1.9	18
1 cm (f)	21.7 - 24.1	640	22.236	0.110	2.3	22
24 ghz (f)	21.7 - 24.1	534	23.801	0.118	1.9	18
7 mm	41.0 - 45.0	1181	43.124	0.090	(h) 6	40
3 mm (g)	80.0 - 90.0	4236	86.2	0.033	(i) 30	(l) 254

- **No coverage of K- or Ka-band TT&C allocations**
- **~ 35% T_{sys} degradation at X band w/ dichroic**

VLBA Observational Status Summary 2019A

Objective

Wide-Band VLBA Receiver System for Astrometry and Navigation

- **International Celestial Reference Frame is now multi-wavelength**
- **VLBA is key asset in constructing current and future instances of ICRF,**
- **… but no coverage at bands relevant to spacecraft tracking**
- **Beginning technology development toward prototype wide-band receiver system for reference frame development and maintenance, with eye toward testing on VLBA**

Technology Development for the North America Array

Background I (FY16--FY18)

North America Array Receiver Package

System Requirements

- **Continuous coverage for 8-48 GHz**
- **T_{rx} = 30--40 K**

  T_{sys} of 34 K @ 10 GHz and 45 K @ 30 GHz required
- **Dual polarization**

Assumption

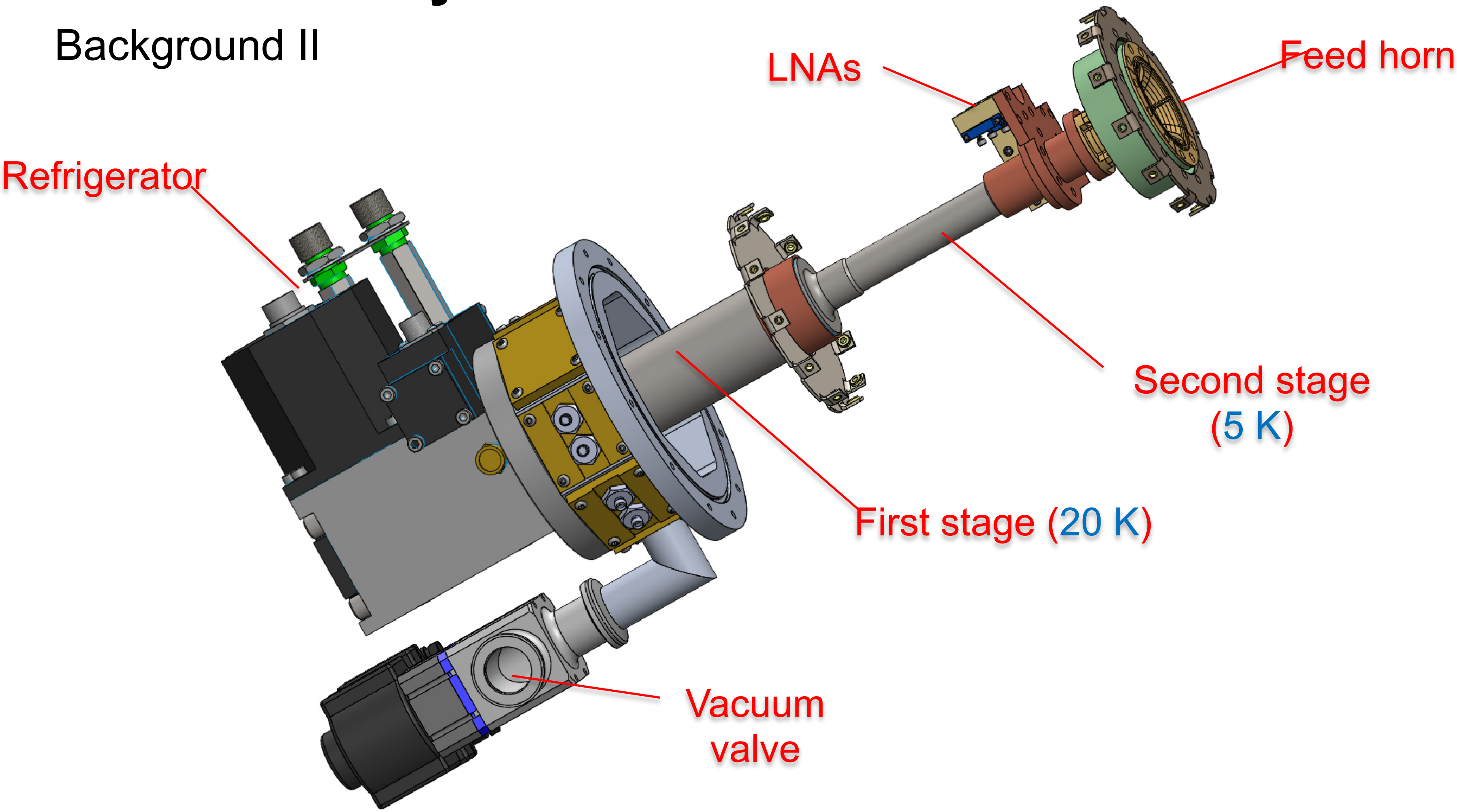
Baseline antenna is offset Gregorian (e.g., MeerKAT antenna) scaled to 18 m diameter with f/D = 0.55

Design considerations

- **Compact cryogenic package**
- **Easy to manufacture**
- **Easy to service**
- **Low Cost**

Technology Development for the North America Array

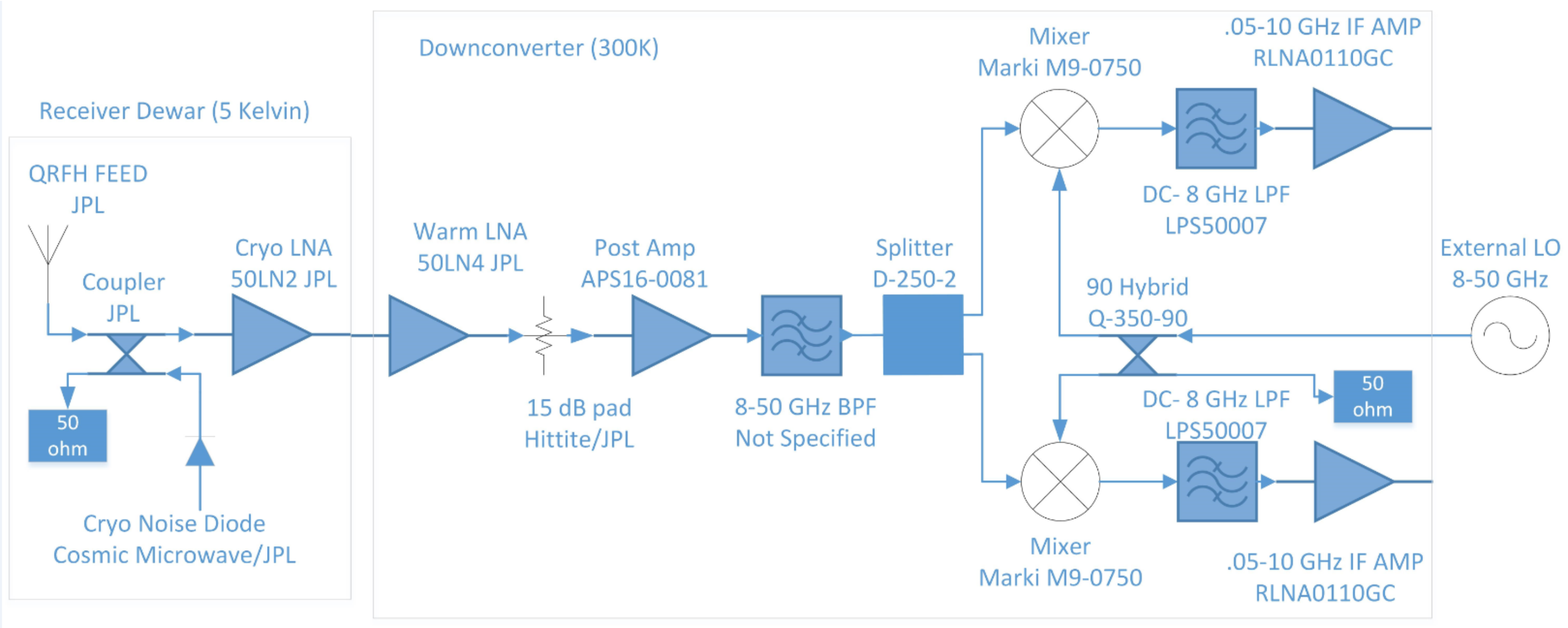
Background II



Technology Development for the North America Array

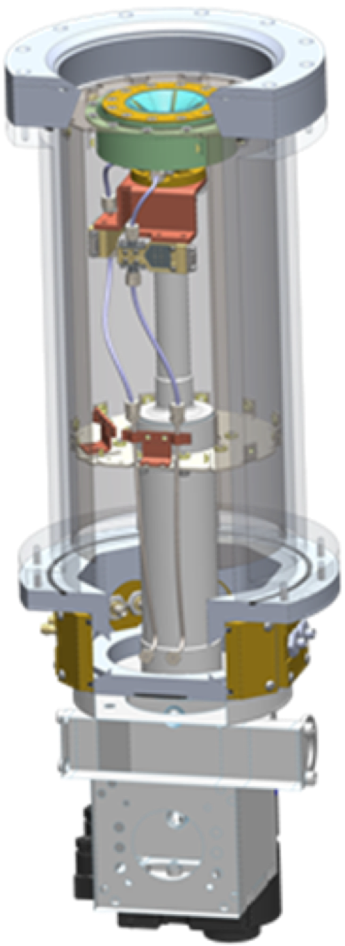
Background III

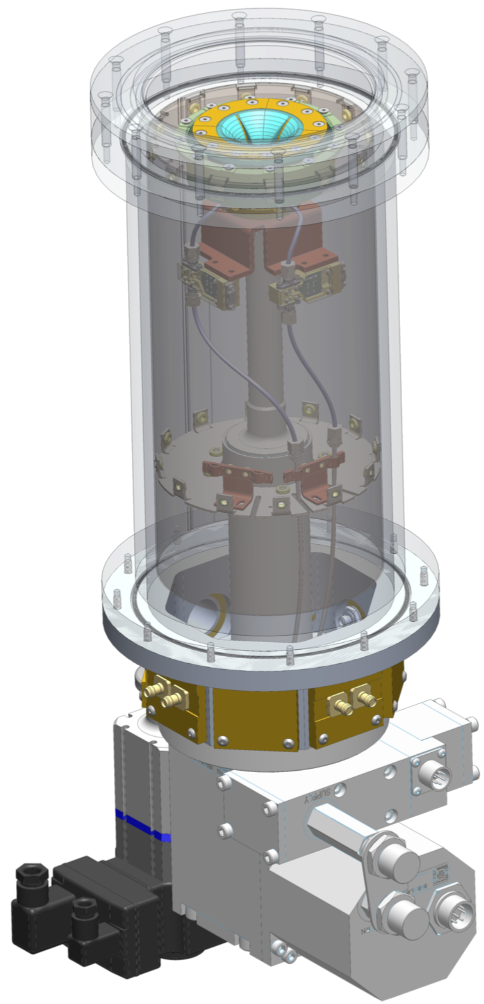
8-48 GHz ultra wide band downconverter for the NAA

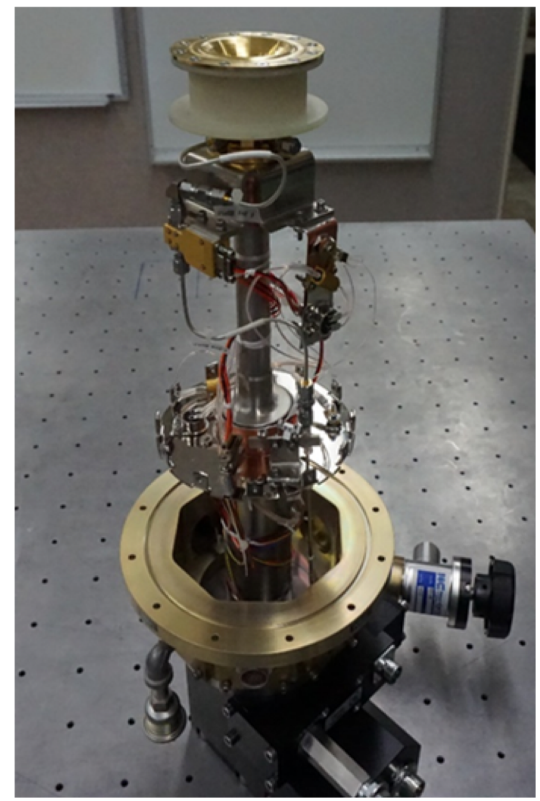


Technology Development for the North America Array

Background IV







Technology Development for the North America Array

Background V

Wide-Band VLBA Receiver System for Astrometry and Navigation

Requirements

North America Array/next-generation Very Large Array

- **Continuous coverage for 8-48 GHz**

  Science-driven requirement

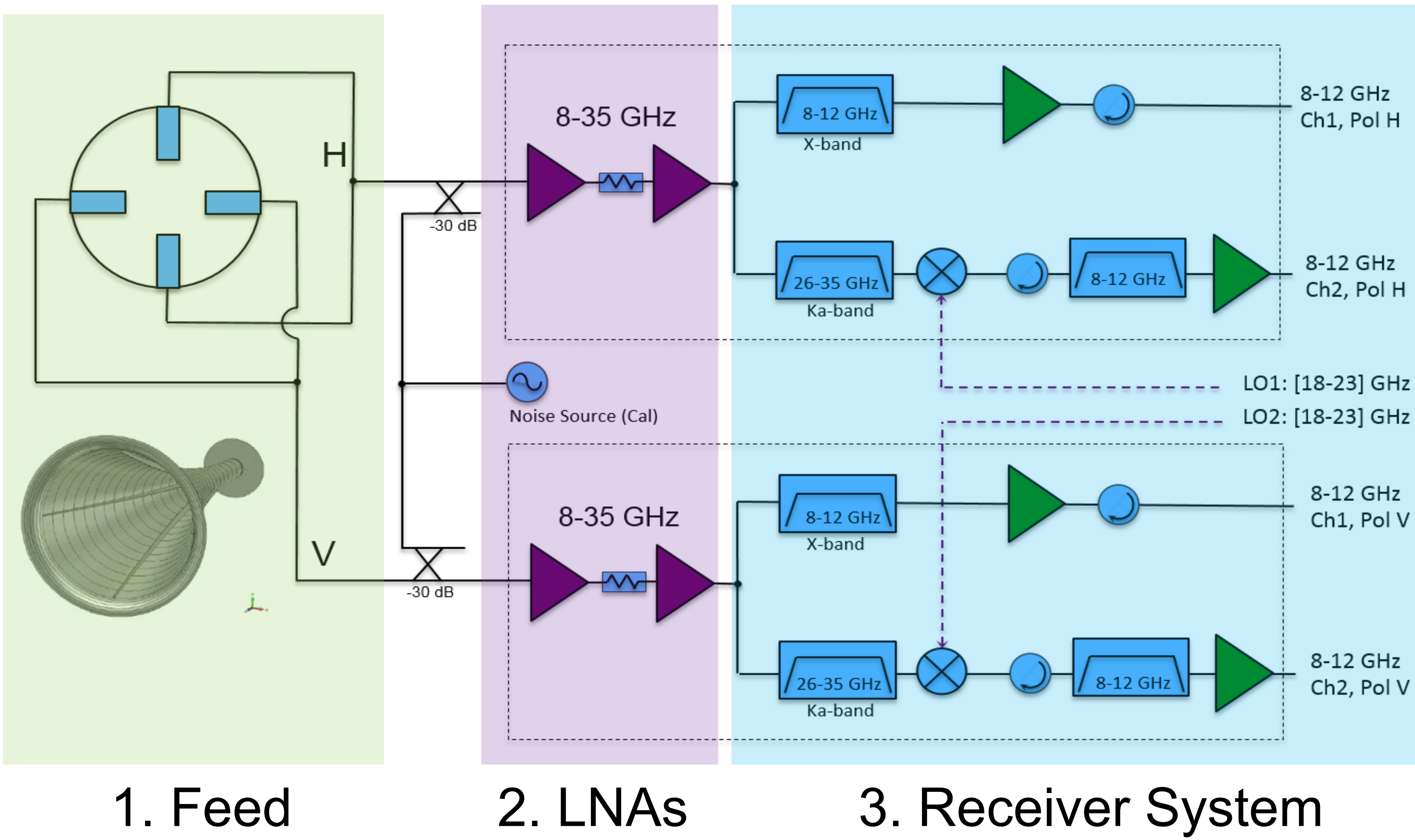
- **Baseline antenna is 18 m diameter offset Gregorian with f/D = 0.55**

Very Long Baseline Array

- **Coverage of 8 GHz to 35 GHz**
  - **Astrometry and navigation-driven requirement**
  - **Radar?**
- **Antenna is 25 m diameter Cassegrain**

VLBA Receiver System

Three Technology Development Components

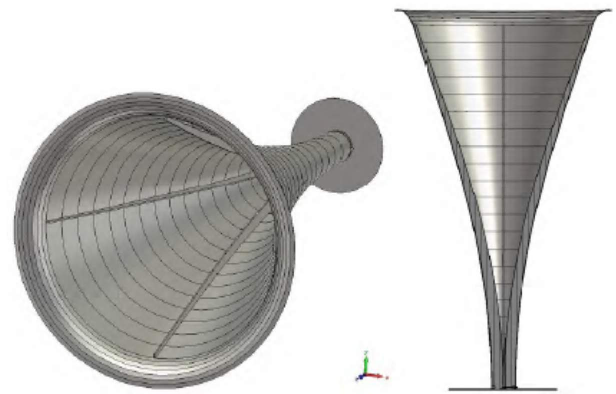


Wideband Feed Development

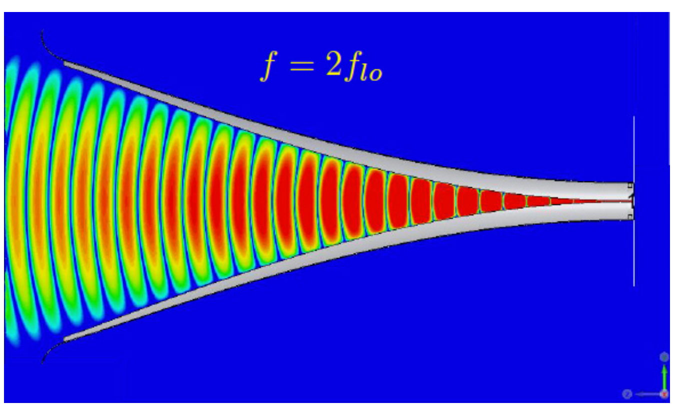
Objectives and Challenges

- **Design feed for 8-35 GHz**
- **Dual polarization**
- **Compatible with VLBA 25 m Cassegrain optics**
- **Quad-ridge flared horn (QRFH)?**

  Based on work of A. Akgiray & S. Weinreb



Gain ~20 dB
$\overline{\eta}_{apt}$ ~ 65%
X_{pol} 10 -20 dB
IRL > -10 dB

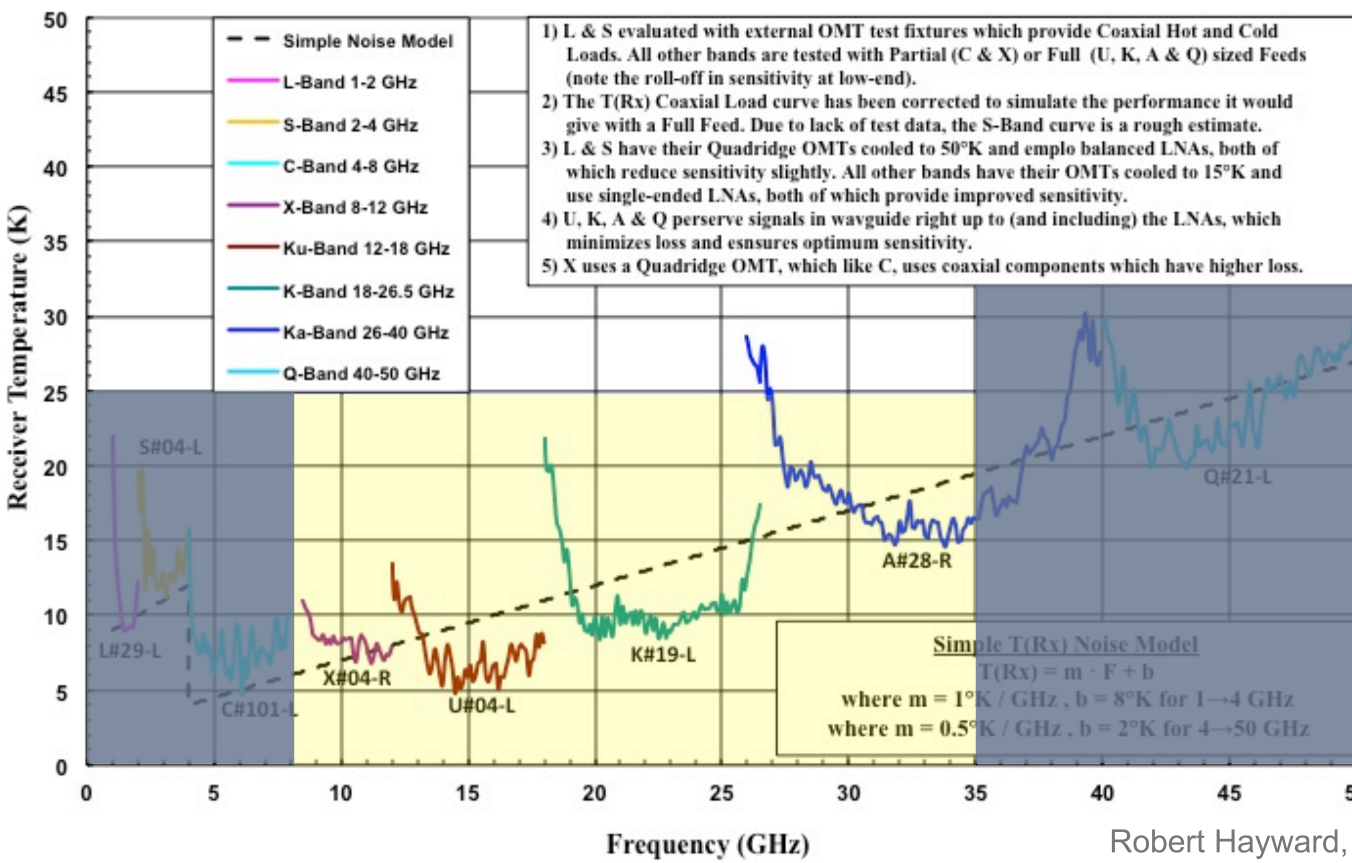


Akgiray, PhD Thesis, Caltech 2013
design intended for DSS-14 with similar optics and f/D

LNA Development

Goal: Receiver Noise Comparable to JVLA

- HEMT LNA-based receivers tuned for narrow individual bands
- Average receiver noise temperatures of 7 K--8 K below 18 GHz, 10 K--20 K from 18 GHz--35 GHz. ***For new Wideband LNA, aim is no more than 20% higher.***
- Goal is ~8 K--24 K from 8 GHz--35 GHz, in one band (not individual receivers)

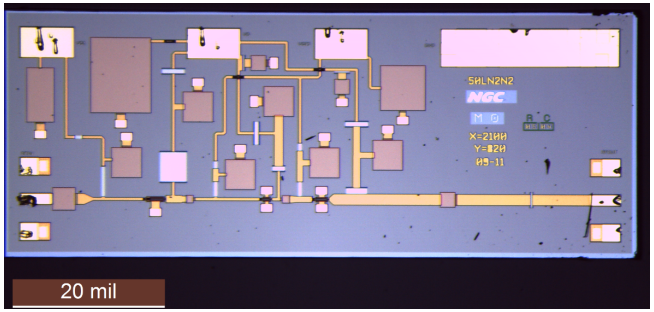


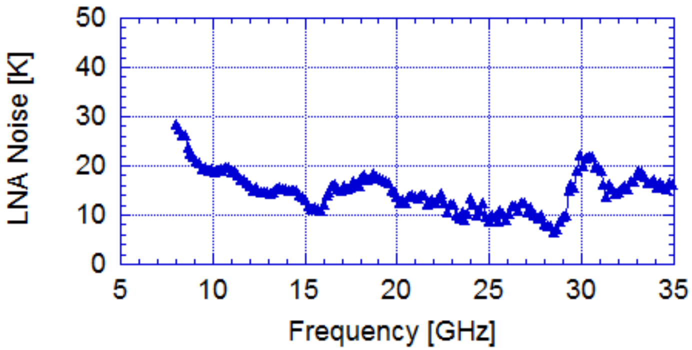
Robert Hayward, "EVLA Receivers" July 2012

Cryogenic Wideband LNA Development

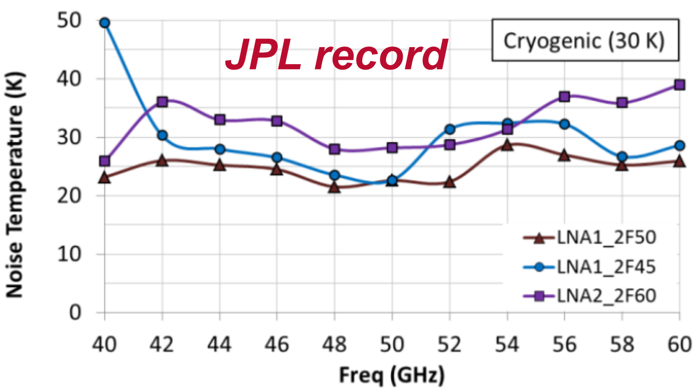
Objectives and Challenges

- **Challenging to achieve low noise LNAs over 8 GHz--35 GHz**
- **JPL has LNA chips from multiple projects, some may be suitable for 8-35 GHz and will be tested**
- ***JPL is world leading in cryogenic MMIC design from 40 GHz--300 GHz***



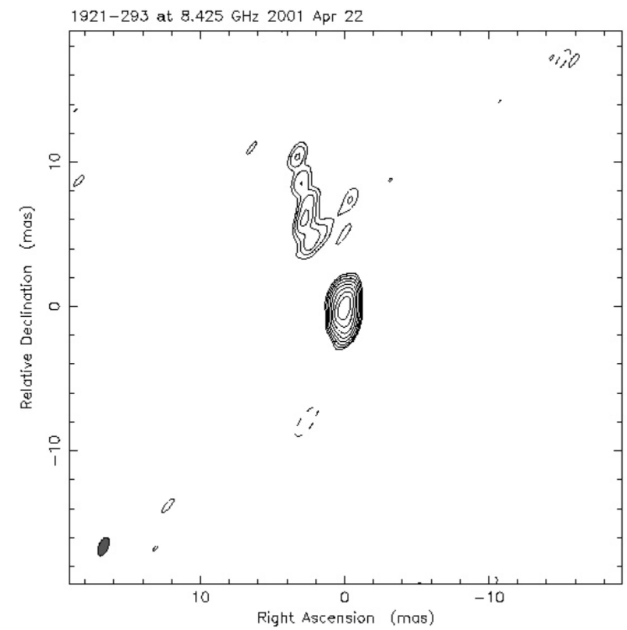


Measured results from 8 GHz--50 GHz LNA from JPL (Bowen 2018) → ***prove concept is possible***



Wide-Band VLBA Receiver System for Astrometry and Navigation

- **Imaging:** ΔDOR navigations benefit from *source images* in order to select most compact components
- ***"Structure" effects*** << ΔDOR 1 nanoradian level
- DSN has only single baselines which prevents source imaging
- At present, **no** instrument in the world that can image at VLBI resolutions *in Ka band*



- **Ephemeris development:** Phase referencing at X- and Ka bands with the VLBA of spacecraft in planetary orbit relative to quasar can track planet's orbit with spacecraft without ΔDOR tones and ***without disrupting telemetry***

Wide-Band VLBA Receiver System for Astrometry and Navigation

Schedule: Year 1

Milestones	Planned Date
Evaluate LNAs 8-35 GHz	Oct -Jan 2019
Design new optimized LNAs & fab	Feb - June 2019
Design Receiver system compatible VLBA	Mar-Jun 2019
Design Wideband Feed compatible - VLBA	July 2019
Fabricate Feed	Aug 2019
Build Receiver	Aug 2019
Test new LNAs	Aug 2019
Test full receiver	Sep 2019

Summary

Wide-Band VLBA Receiver System for Astrometry and Navigation

- Prototype receiver system to provide reference frames for navigation and astrometry
- Critical components
  - Wideband LNA from 8 GHz--35 GHz
  - Wideband dual polarization feed compatible with VLBA